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EVALUATION OF A NEW SONIC ANEMOMETER FOR ROUTINE MONITORING AND EMERGENCY RESPONSE APPLICATIONS

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DISCLAIMER

EVALUATION OF A NEW SONIC ANEMOMETER FOR ROUTINE MONITORING AND EMERGENCY RESPONSE APPLICATIONS

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SUMMARY

Recently, several new sonic anemometers have become available for routine wind measurements. Sonic anemometers avoid many problems associated with the traditional rotating anemometer and vane sets–inertia of moving parts, bearing wear, contamination from dust and ice, frequent maintenance. Without a starting threshold, the sonic anemometer also produces more accurate measurements of wind direction and sigma theta at very low wind speeds. We illustrate these advantages by comparing 20 days of observations from a new sonic anemometer with data from existing cup and vane sensors at the 10-m level of Lawrence Livermore National Laboratory's (LLNL's) meteorological tower.

I. INTRODUCTION

Several meteorological manufacturers, such as Climatronics Corp., Handar Inc., METEK GmbH, Mesa Systems Co. and Gill-SOLENT, have recently developed rugged and nearly maintenance-free sonic anemometers for routine measurements. These new sonic anemometers are distinguished from the more research-grade, 1- and 3-dimensional sonics that are used for measuring sensible heat flux and vertical turbulence, e.g., sensors by Campbell Scientific Inc. and Applied Technologies Inc. For this preliminary study we compared a beta version Handar Model 425 Ultrasonic Wind Sensor to a Met One Model 010/020 cup and vane set, with a focus on parameters important for input to dispersion models.

II. DESCRIPTION OF TOWER SITE

Since the late 1970s, LLNL has collected on-site meteorological data for use in regulatory and emergency preparedness and response dispersion modeling. LLNL is located on the eastern side of the Livermore Valley, about 30 miles east of Oakland, California. The 40-m meteorological tower is located near the northwest corner of LLNL site at an elevation of 174 m. The topography slopes up gently towards the southeast with a grade of approximately 12 m in 1 km.

The tower site is exposed to relatively open fetches consisting mostly of annual grasses for over 150 m in all directions. The surface roughness is about 0.15 m and the zero-plane displacement is 0.5 m.[1] The largest nearby feature is a north to south line of eucalyptus trees about 150 m to the east. A housing development is about 250 m to the west. Commercial buildings are located 300 m to the north.

With an annual average wind speed of 2.6 m/s, LLNL experiences a high frequency of low winds.[2] Based on a 17-year record 27 percent of the 15-minute averages are less than 1 m/s and 50 percent are less than 2 m/s.

III. METHODS

A. Tower Boom and Crossarm Set-up

As shown in Figure 1, the wind sets were mounted on a crossarm located at the end of a 2-m long boom on the west side of the tower at 10 m above the ground. The crossarm was oriented north to south with the Met One wind vane on the south end. The Handar sonic was attached close to the center of the crossarm.

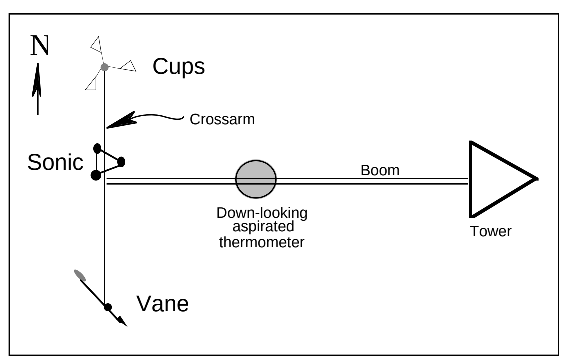

Figure 1. Sensor, crossarm, boom and tower layout.

B. Data Acquisition

We connected the Handar and Met One sensors to separate but identical Handar 540 data loggers running similar acquisition programs synchronized to the same clock. Each 540 logger polled the instruments every second and stored 15-minute averages. The data were transferred periodically via modem to an Atmospheric Release Advisory Capability (ARAC) Sun workstation. Calibration and maintenance of the Met One system was performed according to U.S. Environmental Protection Agency (EPA) guidance.[3,4]

Both loggers recorded the following parameters:

- V, 15-min average horizontal wind speed
- V_m, maximum 1-sec horizontal wind speed
- θ, 15-min average wind direction
- σ_θ, standard deviation of wind direction calculated by the Yamartino[5] method.

Additionally the Met One logger recorded:

- Winds at 40 m
- Temperature at 2, 10 and 40 m
- Precipitation with a tipping bucket rain gauge
- Solar radiation.

C. Met One Cup and Vane System

Table 1 summarizes the manufacturer's specifications. The Met One 010C wind speed sensor is a 3-cup design. The 010C uses a slotted chopper disk to produce a pulsed output that is converted to a voltage proportional to wind speed. We verified the calibration of the wind speed sensor by spinning the shaft at constant speed with a tachometer. The Met One 020C vane uses a precision potentiometer to determine wind direction.

D. Handar Sonic System

The Handar 425 Ultrasonic Wind Sensor uses ultrasound to determine wind speed and direction. A 100-kHz signal is generated by vibrating a cylinder in each of three transducers. The transit time of the signal is measured once per second in the forward and backward directions by each of the three transducers, which are 120 degrees apart. With wind along the sound path, the upwind transit time increases and the downwind transit time decreases. A sensor micro-controller computes wind speed, direction, and the orthogonal components and reports them to the data logger.

IV. RESULTS

A. Study Period

For this preliminary analysis, we collected 1802 15-min values from both data loggers from November 1 to 20, 1996. The weather for the study period was typical for autumn at LLNL with relatively calm winds. As measured by the Met One cups, the average wind speed in the predominant wind direction from the southwest was 2.8 m/s, somewhat stronger than the 2.1 m/s average for the 20 days. While winds are typically stronger during afternoons, the strongest winds during the study period occurred on the mornings of the 17th and the 19th. The average temperature was 12.8°C, and ranged from 4.3 to 22.7°C. One winter storm occurred near the end of the period when 4.57 cm (1.80 inches) of rain fell during the night of November 16-17. The total rain for the study period was 4.70 cm (1.85 inches).

B. Wind Direction Comparisons

The Met One vane and the Handar sonic direction data are very similar when the average wind speed was greater than 2 m/s (N = 816, where N is the number of 15-minute averages). The mean difference is only 2.4 degrees. Figure 2 shows the wind direction difference plotted against the wind direction from the Met One vane. Lockhart[7] attributed this wavy pattern partly to small inaccuracies in the potentiometer. Some of this fluctuation may be due to several other causes, including the tower wake when winds

Table 1. Manufacturers' wind sensor specifications.

Sensor	Starting Threshold (m/s)	Distance Constant (m)	Damping Ratio	Accuracy	Resolution[c]	Max Speed (m/s)
010C cup	0.3	<1.6	---	V: 0.15 m/s or 1%	0.1 m/s	60
020C vane	0.3	<1.0	>0.4[a]	θ: ±3 deg	1 deg	60
425 sonic[b]	0.0	---	---	V: 0.135 m/s or 3%	0.1 m/s	60
				θ: ±2 deg	1 deg	

[a]Estimated using Wang[6]; [b]Preliminary; [c]Includes resolution of logging system

are from 45° to 135°, or by wakes from upwind sensors when the wind directions are along the crossarm or from 0° or 180°. Also the sonic's own transducers may generate a little local turbulence, but this is thought to be negligible.

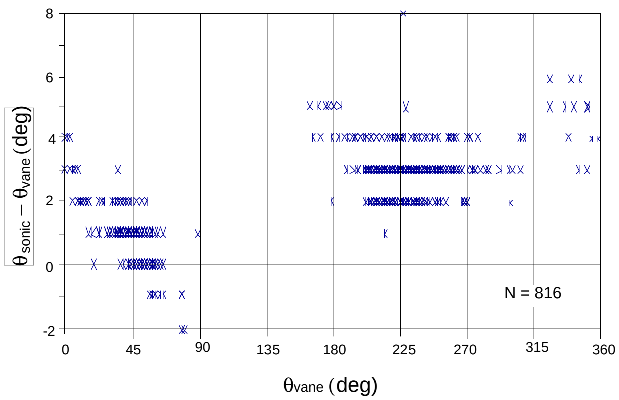

Figure 2. Wind direction difference versus vane direction for $V_{cup} > 2$ m/s.

C. Wind Speed Comparisons

Figure 3 shows a strong correlation ($r^2 = 0.9966$) of wind speed between the sonic and cups. The slope of the linear least-squares regression indicates the sonic consistently outputs 7 percent higher than the cups. This is due to an inaccurate initial calibration of the beta version of the sonic. At this writing, Handar plans to recalibrate the sensor. The 0.05 m/s offset of the regression is small enough to be ignored.

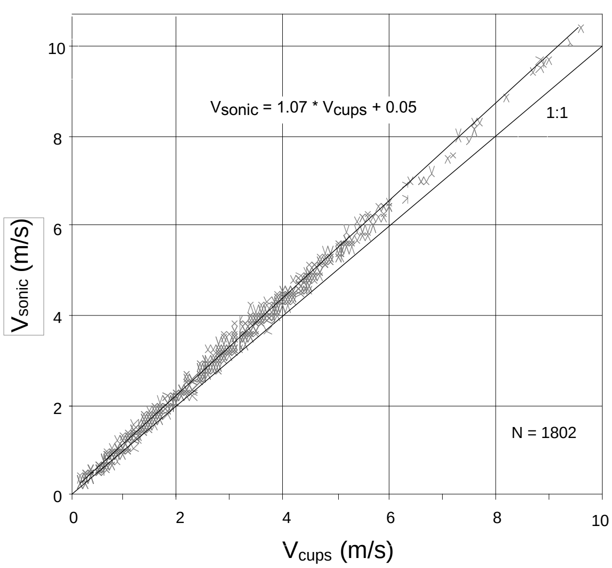

Figure 3. Correlation of V_{sonic} with V_{cups}.

Figure 4 shows the wind speed difference between the sonic and cups, plotted as a percentage of the sonic wind speed against wind speed from the cups. The data points in this diagram line up in a family of curves created by the 0.1 m/s resolution programmed into the logging system.

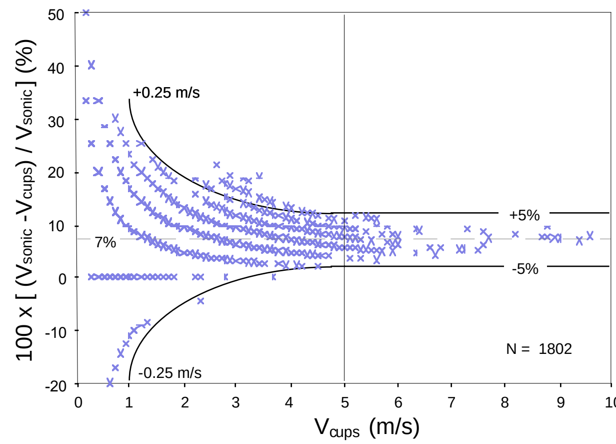

Figure 4. Wind speed difference as a percentage of sonic wind speed.

EPA[3] states that horizontal wind systems should be accurate within 0.25 m/s in the range between the threshold and 5.0 m/s. At higher speeds the error should not exceed 5 percent of the observed speed. The two lines in Figure 4 envelope this accuracy specification after a 7 percent adjustment is applied to the sonic wind speed. Most of the 1802 data points are within the adjusted accuracy envelope.

D. Sigma Theta Comparisons

1. Moderate winds ($V \geq 2$ m/s)

Figure 5 shows how the difference in σ_θ between the sensors varies with wind direction. Sigma theta compared remarkably well when the winds were greater or equal to 2.0 m/s. The root mean square σ_θ difference was just 0.8°. The maximum absolute difference in σ_θ between the two sensors was 4.6°. The largest deviation may be caused by

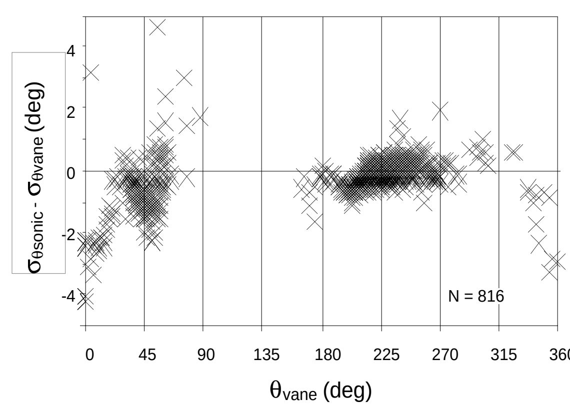

Figure 5. The difference in σ_θ versus vane wind direction.

additional turbulence when the wind is from the north and the vane is in the lee of the cups and sonic sensors.

2. Low winds (V < 2 m/s)

Figure 6 shows that σ_θ from the sonic tends to be greater than the vane at low wind speeds. The large difference in σ_θ at very low winds is caused by the vane's lack of movement below its 0.25 m/s starting threshold and by its insensitivity to very small turbulent eddies. Without a starting threshold the sonic senses smaller wind direction fluctuations at lower wind speeds. Detailed time series of low wind periods, not included in this paper, and previous sonic-vane comparisons[8] indicate that sonics consistently produce larger σ_θ than the vanes during low winds.

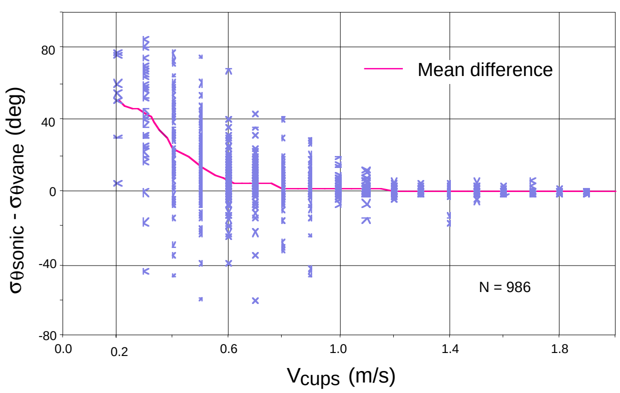

Figure 6. Difference in σ_θ versus V_{cups} for $V_{cups} < 2$ m/s.

V. IMPLICATIONS FOR DISPERSION MODELING

Without a threshold speed, a sonic anemometer can collect more wind data with greater accuracy at very low wind speeds than cup and vane systems. This is advantageous at a low wind speed site such as Livermore, California. Better definition of near calm conditions allow dispersion models to be used more reliably at lower wind speeds.[9] This is especially important in the consideration of worst case conditions for environmental analyses or limited dispersion during accidents. A sonic also is advantageous for directly measuring turbulence parameters, σ_θ, σ_u, σ_v, σ_ϕ, and σ_w, which provide site-specific inputs into dispersion models, rather than relying on generalized parameterizations of stability class.[10]

Additional study of the Handar sonic is planned in 1997, including a wind tunnel calibration and more detailed field comparisons.

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